An STM-based Atomic-Precision Lithography Tool

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Hydrogen Depassivation Lithography (HDL) using an STM tip has become established as a method for atomic-precision patterning for 2D dopant-based devices. Patterning is required over multiple length scales, as shown in Fig.1. For devices such as the 'single atom transistor'[1], single dopant atoms need to be placed precisely relative to other device elements, such as electrodes, gates, and other single dopant atoms. For 2D quantum metamaterials [2], arrays of dopant patches, either single dopants or small clusters of dopants, must be placed with atomic precision relative to each other, as the coupling strength changes significantly with each dimer row (0.768 nm) of spacing. At a larger length scale, these atomic-level device elements need to be connected to μm-scale bond pads, which are used to connect the buried dopant structures to the outside world. With multiple dopant species, such as in bipolar junction transistors, the second dopant pattern must be aligned with atomic precision to the first dopant pattern. We have developed an automated STM lithography control system, ZyVector, with novel capabilities such as automated writing from patterns input from SVG CAD files, as shown in Fig. 2, so as to improve the capability of a standard STM for patterning atomically-precise devices.

However, patterning the devices is merely one step in the overall process. After patterning, the patterns are exposed to dopant precursor gases, which are annealed to incorporate the dopants. Once the whole device is complete, it is then buried in epitaxial Si. This complete process has become known as Atomically Precise Advanced Manufacturing (APAM)[3].

Now, we are taking the next step towards a complete APAM tool. ZL-1 is a UHV STM system with the additional chambers and components for dopant precursor gas dosing and Si MBE. The STM can either be operated with conventional STM tips, or in hybrid mode, using a 1DOF MEMS device to provide a much more sensitive Z actuation, allowing for a 10x speedup in both imaging and lithography[4].

The conceptual design of ZL-1 is shown in Fig. 3 below. Tips and samples are brought in through a fast entry lock into a Preparation chamber, where tips and samples are degassed, and H-terminated samples are prepared. They are then transferred into the STM chamber, where the patterning takes place. The best attainable vacuum is maintained in this part of the system, so as to produce the cleanest devices. Precursor gas dosing can be done in the STM chamber, or in an optional dosing chamber, and annealing and Si MBE then occur in the Si deposition chamber connected to the STM. For bipolar devices, it is likely that each precursor gas will require its own dosing chamber.

[1] M. Fuechsle, J. A. Miwa, S. Mahapatra, H. Ryu, S. Lee, O. Warschkow, L. C. L. Hollenberg, G. Klimeck, and M. Y. Simmons, *Nat Nano* **7** 242-246 (2012)

[2] https://www.zyvexlabs.com/2d-workshop/workshop-overview/

[3] Bussmann, E. *et al. MRS Bull.* **2021**, *46*, 1–9.

[4] Alipour, A.; Coskun, M. B.; Moheimani, S. O. R. *J. Microelectromechanical Syst.* **2021**, *30*, 271–280.

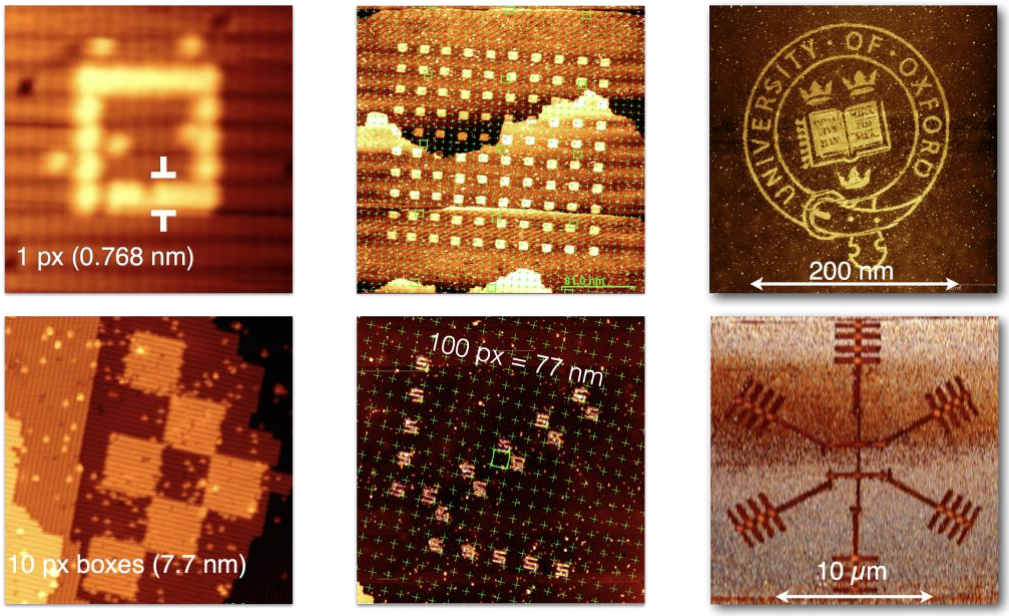

Figure 1: ZyVector performs automated patterning from single-nm to µm-scale.

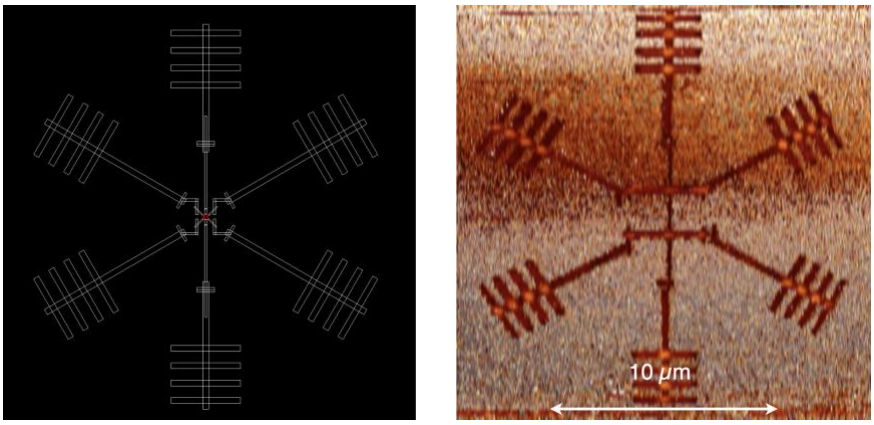

Figure 2: A Hall Bar structure is drawn in SVG format, and then written automatically.

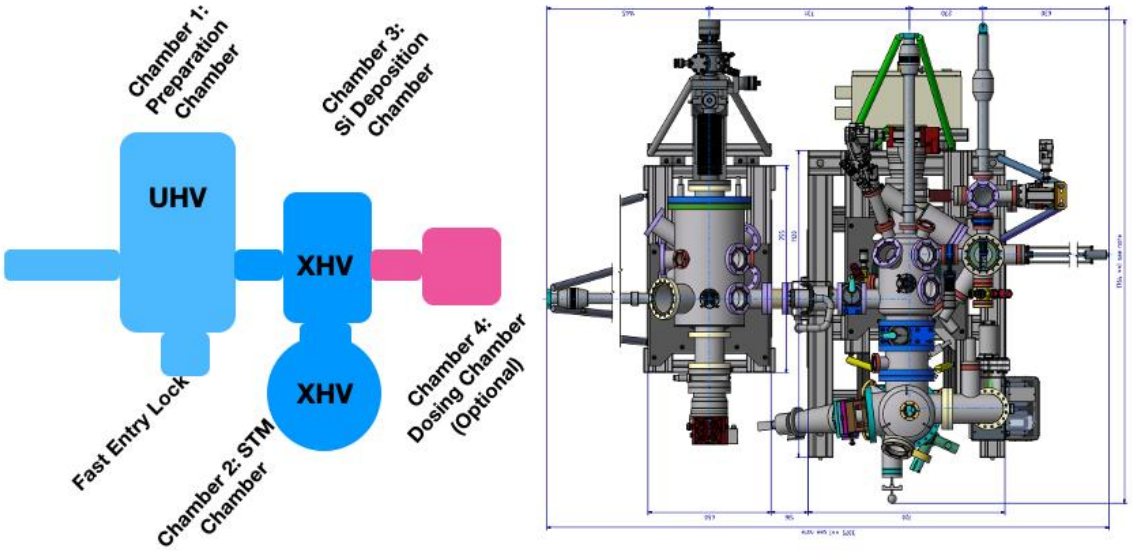

Figure 3: Concept of ‘ZL-1’, a complete APAM lithography tool.